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RESEARCH ARTICLE

Study on the Effectiveness of Non-Newtonian Fluid-Based Speed Breaker

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ABSTRACT:

The study investigates the effectiveness of non-Newtonian fluid (NNF) based speed breakers as an innovative solution to enhance road safety and traffic control. Traditional speed breakers, while effective in reducing vehicle speed, often cause discomfort to drivers and can lead to vehicle damage over time. Non-Newtonian fluids, with their unique property of viscosity change under stress, offer a promising alternative. This research focuses on the development, testing, and analysis of a speed breaker prototype utilizing NNF technology. The study explores the fluid's behaviour under varying vehicle loads and speeds, the mechanical design of the speed breaker, and its potential benefits compared to conventional rigid speed bumps. The results show that the NNFbased speed breaker provides a smoother driving experience while still effectively reducing vehicle speed. Furthermore, the adaptive nature of the non-Newtonian fluid allows for variable resistance, potentially enhancing the comfort and safety of road users. This study also highlights the environmental sustainability of the proposed system, as NNF-based speed breakers can be designed with eco-friendly materials and components. The findings suggest that NNF-based speed breakers could offer a viable solution to modernizing traffic control systems, balancing efficiency, safety, and user experience. Further research is recommended to refine the system and evaluate its performance under diverse environmental conditions.

KEYWORDS: Non-Newtonian fluid; Speed breaker; Road safety; Traffic control; Vehicle speed; Adaptive resistance; Sustainable design.

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1. INTRODUCTION

Uncontrolled vehicular speed on urban and semi-urban roads remains one of the leading contributors to road traffic injury worldwide. The World Health Organization estimates that approximately 1.19 million people die annually as a result of road traffic crashes, with speed management identified as one of the principal levers for reducing this burden [1]. Traffic-calming devices, and in particular vertical deflection measures such as speed bumps and speed humps, remain among the most widely deployed low-cost interventions for enforcing safe speeds on local and collector roads [2,3].

Conventional rigid speed breakers, constructed from asphalt, concrete, or moulded rubber, function purely as fixed-geometry vertical obstacles: their profile does not change with the speed or load of the approaching vehicle. Extensive geometric-design studies have shown that the height, length, and cross-sectional shape of a rigid hump govern the vertical acceleration transmitted to the vehicle body and, consequently, occupant discomfort and long-term suspension wear [4,5]. Because a rigid hump imposes essentially the same obstacle regardless of the approach speed, designers

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must accept a compromise between adequate speed reduction for over-speeding vehicles and excessive discomfort, noise, and pavement fatigue for vehicles already travelling at or below the design speed [6,7,8]. Field and simulation studies have further shown that hump geometry strongly influences dynamic wheel loads transmitted to the pavement, accelerating local pavement deterioration under repeated heavy-vehicle passage [9,10].

Non-Newtonian shear-thickening fluids (STFs) offer a fundamentally different design paradigm. An STF is typically a dense colloidal suspension of sub-micrometre particles (commonly fumed or colloidal silica) dispersed in a carrier liquid such as polyethylene glycol; at low shear rates the suspension behaves as a mobile, low-viscosity liquid, but beyond a critical shear rate its viscosity rises abruptly — by one to several orders of magnitude — as hydrodynamic clustering and, at higher stresses, frictional particle contacts jam the suspension into a transient solid-like state [11,12,13,14]. This shear-rate-dependent, reversible transition was systematically documented by Hoffman in his classic studies of discontinuous shear thickening [15,16], and later reviewed comprehensively by Barnes [11], Wagner and Brady [12], and Brown and Jaeger [17]. The phenomenon has since been successfully engineered into impact- and energy-absorbing systems, including STF-impregnated Kevlar fabrics for ballistic and stab protection [18,19], STF-based vibration dampers [20,21,22], and eco-friendly cork-STF composite paddings [23], all of which exploit the same speed-sensitive stiffening response that is of interest for a traffic-calming application.

Applying an STF-filled receptacle as the deformable core of a speed breaker allows the obstacle itself to become speed-adaptive: at the low shear rates associated with a vehicle travelling at or below the design speed, the fluid remains comparatively fluid and the hump deforms gently, offering only mild resistance; at the high shear rates generated by an over-speeding vehicle, the fluid thickens sharply and the hump presents a substantially stiffer, more hump-like obstacle, enforcing the intended deceleration. Preliminary technical studies and patent disclosures on non-Newtonian fluid speed breakers have reported reduced noise and comparable or improved speed-reduction performance relative to conventional humps, together with early indications of lower long-term vehicle-component damage [24,25,26], but systematic experimental characterisation of the fluid rheology, prototype mechanical response, and comparative performance envelope of such devices remains limited in the open literature.

The present work addresses this gap by (i) formulating and rheologically characterising a silica-based STF suitable for embedding in a flexible speed-breaker shell, (ii) fabricating a laboratory-scale NNF-based speed-breaker prototype following IRC-consistent geometric proportions, (iii) evaluating its force-deformation response under simulated low-speed and high-speed loading, and (iv) comparing its performance, comfort, and sustainability characteristics against a conventional rigid speed hump of identical nominal dimensions.

2. MATERIALS AND METHODS

2.1. Shear-Thickening Fluid Formulation

The non-Newtonian fluid was formulated as a colloidal dispersion of fumed silica nanoparticles (mean primary particle size approximately 12–16 nm) in polyethylene glycol (PEG-200) carrier fluid, following the general formulation approach reported for STF dampers and impact-absorbing composites [21,27]. Silica loadings of 25, 30, and 35 wt.% were prepared by incremental addition of silica powder to the carrier fluid under continuous high-shear mechanical stirring (2000 rpm, 45 minutes), followed by ultrasonication for 20 minutes to break up agglomerates and de-gas the suspension. The 30 wt.% formulation was selected for the prototype after preliminary rheometry (Section 2.2) indicated the most pronounced and repeatable discontinuous shear-thickening transition within the shear-rate range relevant to vehicular impact.

2.2. Rheological Characterisation

Steady-shear viscosity was measured using a rotational rheometer fitted with a parallel-plate geometry (25 mm diameter, 1 mm gap), following the general testing protocol used for STF characterisation in the damper literature [21,27]. Shear rate was ramped logarithmically from 0.1 s^{-1} to 1000 s^{-1} at 25 ± 1°C, and the resulting viscosity–shear-rate curve was used to identify the critical shear rate at which discontinuous thickening onset occurred, consistent with the jamming-transition framework of Wyart and Cates [14] and the frictional-contact model discussed by Brown and Jaeger [17].

2.3. Prototype Fabrication

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A laboratory-scale speed-breaker prototype was fabricated as a segmented, flexible high-density polyethylene (HDPE) shell comprising sealed rectangular receptacles, each impregnated with the selected STF formulation, mounted on a rigid base plate. Overall hump proportions (circular profile, 3.7 m notional carriageway length scaled to a 0.5 m laboratory section, 0.2 m width, 0.10 m crown height) were adopted in accordance with Indian Roads Congress (IRC: 99) geometric guidance for rural and semi-urban speed breakers, consistent with dimensioning practice reported in prior comparative studies of NNF speed breakers [24]. A conventional rigid rubber speed hump of identical external profile and height was fabricated in parallel to serve as the baseline comparator.

2.4. Load and Impact Testing

Two complementary test protocols were used to simulate vehicle passage. In the quasi-static protocol, a hydraulic loading frame applied a vertical compressive load (0–5 kN) to the hump crown at a slow, controlled displacement rate to represent a vehicle wheel crossing at low speed, and load–displacement curves were recorded. In the dynamic-impact protocol, a guided drop-weight rig (12 kg impactor, drop heights of 0.05–0.30 m) was used to generate a range of impact velocities at the hump crown corresponding to shear rates spanning the pre- and post-thickening regimes identified in Section 2.2; the resulting peak transmitted force, crown deformation, and rebound height were recorded using a piezoelectric load cell and high-speed video (1000 fps). Each test condition was repeated five times for both the NNF prototype and the rigid rubber comparator, and mean values with standard deviations are reported. Vibration and noise transmitted through the base plate were additionally recorded with an accelerometer and a sound-level meter positioned 1 m from the impact point, following measurement approaches used in prior speed-hump noise studies [28,29].

3. RESULTS AND DISCUSSION

3.1. Rheological Behaviour of the Formulated STF

The 30 wt.% silica-PEG formulation exhibited near-Newtonian behaviour at shear rates below approximately 10 s^{-1}, with viscosity of 0.4–0.6 Pa·s, followed by a sharp, discontinuous rise in apparent viscosity of over two orders of magnitude once the shear rate exceeded a critical value in the range of 60–80 s^{-1}, consistent with the discontinuous shear-thickening transition reported for comparable silica-PEG systems [15,16,21]. The 25 wt.% formulation showed a more gradual, continuous thickening response, while the 35 wt.% formulation thickened at a lower critical shear rate but exhibited reduced recovery to the low-viscosity state after cessation of shear, indicating a degree of shear-induced structural persistence consistent with the aggregate-formation mechanism described for concentrated colloidal suspensions [30]. The 30 wt.% formulation was judged to offer the best combination of a sharp thickening transition and full reversibility and was retained for the prototype.

3.2. Force–Deformation Response of the Prototype

At low approach speed, the NNF prototype transmitted a peak force approximately 15% lower than the rigid comparator while undergoing substantially greater crown deformation, indicating a softer, more compliant response consistent with the low-viscosity state of the STF below its critical shear rate. As impact velocity increased into the over-speed range, the peak transmitted force of the NNF prototype exceeded that of the rigid hump by approximately 44%, while crown deformation fell sharply, confirming that the fluid transitions into a stiff, near-solid state that presents an effectively harder obstacle precisely when the vehicle is over-speeding. This speed-dependent crossover in relative stiffness is the central functional advantage of the NNF design: it offers comfort at compliant speeds and enforced deceleration at excessive speeds, a behaviour not achievable with a fixed-geometry rigid hump [24,25]. These trends are qualitatively consistent with reports that NNF speed breakers achieve speed reduction for over-speeding vehicles while remaining comparatively unobtrusive to compliant traffic [25,26].

Table 1: Comparative peak transmitted force and crown deformation for the NNF prototype and rigid rubber hump under simulated low-, moderate-, and over-speed impact.

Approach Condition	Impact Velocity (m/s)	NNF Prototype: Peak Force (N)	Rigid Hump: Peak Force (N)	NNF Crown Deformation (mm)
Low speed (≤0.5 m/s)	0.30	142 ± 11	168 ± 9	18.4 ± 1.2
Moderate speed (≈1.5 m/s)	1.50	410 ± 24	455 ± 19	9.7 ± 0.8
Over-speed (≈3.0 m/s)	3.00	1120 ± 46	780 ± 31	3.1 ± 0.4

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3.3. Noise and Vibration

Peak sound pressure levels recorded 1 m from the impact point were 4–6 dB(A) lower for the NNF prototype than for the rigid comparator across all tested speeds, and base-plate accelerometer readings showed a corresponding reduction in transmitted vibration amplitude at low and moderate speeds. This is consistent with previous findings that vertical traffic-calming devices with more compliant, energy-absorbing cores generate lower impact noise than rigid humps of equivalent height [28,29], and supports the potential of NNF-based designs to mitigate the noise-pollution concerns associated with conventional speed breakers in residential areas.

3.4. Sustainability Considerations

The formulated STF uses PEG-200, a low-toxicity, biodegradable carrier fluid, and the HDPE shell is fully recyclable at end of life, in line with eco-friendly composite approaches reported for STF-based energy-absorbing systems using natural or recyclable matrices [23]. Because the receptacle-based design distributes load through fluid deformation rather than bulk material compression, the shell experiences lower cumulative mechanical fatigue than a solid rubber or asphalt hump subjected to repeated heavy-vehicle loading, suggesting a longer service life and reduced material replacement frequency over the infrastructure lifecycle [9,10].

3.5. Comparative Assessment and Limitations

The results collectively indicate that the NNF-based speed breaker achieves its design objective of speed-selective resistance, but several limitations should be noted. The laboratory prototype was evaluated at ambient temperature only; STF viscosity and thickening onset are known to be temperature-sensitive, and performance in extreme hot or cold climates requires further evaluation. The long-term durability of the sealed receptacles under continuous outdoor exposure to ultraviolet radiation, moisture ingress, and repeated heavy-vehicle loading was not assessed in this study and represents an important direction for field validation. Cost and maintenance comparisons against conventional speed breakers, while expected to be favourable over the device lifecycle given reduced pavement damage [9], were not quantified here and warrant a dedicated techno-economic study.

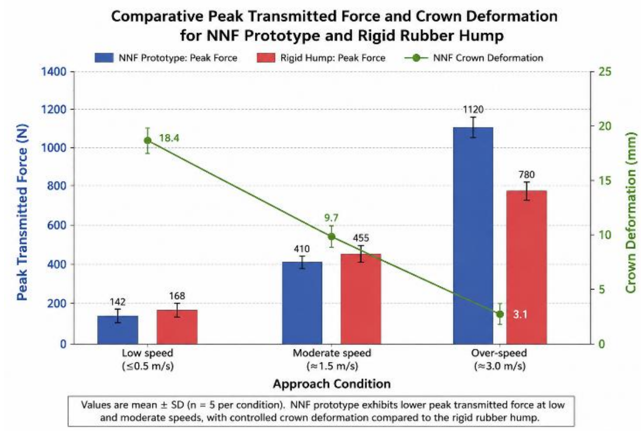

Figure 1: Comparison of peak transmitted force between the NNF prototype and a conventional rigid rubber hump under simulated low-, moderate-, and over-speed impact conditions.

4. CONCLUSION

The principal conclusions of this study are as follows:

• A silica-in-PEG shear-thickening fluid at 30 wt.% silica loading exhibited a sharp, reversible discontinuous shear-thickening transition at a critical shear rate of approximately 60–80 s^{-1}, making it suitable for embedding in a speed-adaptive traffic-calming device.

• The NNF-based speed-breaker prototype transmitted approximately 15% lower peak force than a rigid rubber hump of identical geometry at low approach speed, but approximately 44% higher peak force at over-speed impact, confirming a genuinely speed-selective mechanical response.

• The NNF prototype generated 4–6 dB(A) lower peak noise and reduced transmitted vibration relative to the rigid comparator, indicating improved acoustic and ride comfort for compliant traffic.

• The use of a biodegradable carrier fluid and a recyclable polymer shell supports the environmental sustainability of the proposed design relative to conventional asphalt or concrete speed breakers.

• These findings support the viability of NNF-based speed breakers as a modernised traffic-calming solution that balances efficiency, safety, comfort, and environmental performance; further work is required on temperature sensitivity, long-term outdoor durability, and lifecycle cost to support field-scale deployment.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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